Original Article

Effects of plantar static pressure distribution in subject with bilateral hallux limitus: a detailed case-control study

Natalia Tovaruela-Carrión[1], Ricardo Becerro-de-Bengoa-Vallejo[2], Marta Elena Losa-Iglesias[3], Daniel López-López[4], Juan Gómez-Salgado[5,6], Javier Bayod López[7]

[1]Faculty of Nursing, Physiotherapy and Podiatry, University of Seville, Seville, Spain; [2]Faculty of Nursing, Physiotherapy and Podiatry, Complutense University of Madrid, Madrid, Spain; [3]Faculty of Health Sciences, Universidad Rey Juan Carlos, Madrid, Spain; [4]Research, Health and Podiatry Group, Department of Health Sciences, Faculty of Nursing and Podiatry, Industrial Campus of Ferrol, Universidade da Coruña, Ferrol, Spain; [5]Department of Sociology, Social Work and Public Health, Faculty of Labour Sciences, Universidad de Huelva, Huelva, Spain; [6]Safety and Health Postgraduate Program, Universidad Espíritu Santo, Guayaquil, Ecuador; [7]Applied Mechanics and Bioengineering Group (AMB), Aragon Institute of Engineering Research (I^3A), Centro de Investigación Biomecánica en Red CIBER-BBN, Universidad de Zaragoza, Zaragoza, Spain

Contributions: (I) Conception and design: All authors; (II) Administrative support: All authors; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Daniel López-López, PhD, MPH, BSC, MsC, DP. Research, Health and Podiatry Group, Department of Health Sciences, Faculty of Nursing and Podiatry, Industrial Campus of Ferrol, Universidade da Coruña, R/Dr. Vázquez Cabrera, s/n., 15403 Ferrol, Spain. Email: daniellopez@udc.es.

Background: Hallux limitus (HL) is defined as the restriction of dorsiflexion (DF) in the first metatarsophalangeal joint (IMTFJ) under closed kinetic chain conditions, where the distal segment is fixed and the foot is in contact with the ground. This biomechanical condition compromises the Windlass mechanism during the propulsive phase of gait, generating pain and functional disability. Therefore, the aim of this research was to examine the aspect of foot shape linked to distribution of static plantar pressure in individuals with bilateral HL compared to subjects with normal foot.

Methods: A total of 90 subjects participated in this case-control study, divided into two groups: 45 individuals with bilateral HL and 45 healthy individuals without any known foot pathology. A portable pressure platform was used to measure each subject's static plantar pressure.

Results: Individuals with HL showed significantly increased contact surface in the forefoot (left: 36.67±8.30 *vs.* 28.91±7.94 cm^2) and heel (left: 30.85±7.70 *vs.* 24.55±7.17 cm^2; right: 31.01±7.98 *vs.* 25.71±7.64 cm^2), and higher medium peak pressure in the left foot (HL: 27.90±5.41 kPa *vs.* control: 22.58±6.57 kPa) ($P<0.001$).

Conclusions: Individuals with bilateral HL showed altered static plantar pressure distribution and increased contact surface in the forefoot and heel compared to healthy controls. Limitations include sex imbalance between groups and lack of dynamic data. These findings may reflect compensatory adaptations and support the need for tailored interventions to improve foot function in this population.

Keywords: Foot disease; gait analysis; hallux limitus (HL); instability; plantar pressure

Submitted Apr 16, 2025. Accepted for publication Jul 03, 2025. Published online Aug 12, 2025.
doi: 10.21037/qims-2025-907
View this article at: https://dx.doi.org/10.21037/qims-2025-907

Introduction

Hallux limitus (HL) is described as a restriction in dorsiflexion (DF) of the proximal phalanx of the hallux relative to the first metatarsal (1,2). This restriction becomes evident specifically in a closed kinetic chain, such as during walking or standing, where the ground reaction force and joint compression affect joint mechanics. In an open kinetic chain, such as during passive movement without weight bearing, the physiological range of motion is often preserved (3-6). This distinction underscores the importance of assessing HL under functional load-bearing conditions. The DF movement of the first metatarsophalangeal joint (IMTFJ) is essential for walking, particularly during the propulsion phase of gait, where adequate joint mobility contributes to foot stabilization and efficient push-off (2,7-9). While this phase is often described dynamically in gait analysis (10-12), the present study focuses on static plantar pressure distribution as a functional indicator of load-bearing alterations associated with HL. In healthy gait, the IMTFJ dorsiflexes approximately 58°, and the hallux can bear up to 60% of body weight during late stance. However, in HL, limited DF can shift plantar pressures and provoke biomechanical compensations, including pronation, altered center of mass progression, or changes in contact surface (2,7). HL is the second most frequent reason of arthritic pathology in the adult population and its incidence increases with age (13). However, we know little about the underlying causes and management strategies for HL, since it is recognized as a multifactorial condition, and among these risk factors, we can find increased mobility in the first ray, longer metatarsals, a raised first metatarsal, hallux valgus (HV) interphalangeus, being female, and a family history of the condition (14,15). In addition to other known risk factors, first-ray hypermobility (FRH) has been recognized as an important biomechanical contributor to the development of HL. FRH is characterized by excessive dorsal movement of the first metatarsal relative to the medial cuneiform, compromising the stability of the medial column of the foot (16,17). This instability may reduce the efficiency of the foot's structural support mechanisms, leading to altered load distribution. Although the precise role of FRH as a cause or consequence of hallux deformities remains under discussion, its presence highlights the importance of considering three-dimensional foot mobility and morphology in HL diagnosis and management (16). When the limitation worsens and the range of motion is blocked, the sagittal plane is affected and it is common for the pathology to degenerate into HV or hallux rigidus (HR) (11,18). Progression to HR is associated with significant physical limitations, persistent discomfort, and a marked impact on daily activities and overall well-being (19-21).

When DF is restricted, the joint's inability to perform its normal motion during weight-bearing may lead to altered load distribution across the foot. As a result, compensatory mechanisms are triggered to maintain forward progression and stability. These secondary compensations can cause local symptoms such as metatarsalgia and sesamoiditis, but they can also cause discomfort in the ankles, knee, legs, hips or lumbar area (22), making it difficult to put on shoes, a slower pace when walking, greater unsteadiness, and improper posture (19,23). Each of these factors can influence everyday tasks, leading to a detrimental effect on overall health related life quality (19,24).

Because of the modification of the body and the center of mass, the plantar pressures that can be observed by baropodometry are also modified with respect to physiological patterns, increasing or decreasing plantar pressure (12,22,25). These pressure platforms are devices that are used to assess and evaluate plantar pressure both statically and dynamically, to measure the pressure forces exerted by the feet. Previous studies of plantar pressures in subjects with HL compared to healthy subjects have shown an increase in pressure under the hallux, lesser toes and 3rd-4th metatarsal (26), in other studies HL has been related to an increase in tension in the plantar fascia, as well as with pronated feet due to a biomechanical alteration (2,8,27).

Despite existing research into plantar pressure alterations in HL under dynamic conditions, there is a lack of studies assessing how HL affects static plantar pressure distribution and foot morphology under load-bearing conditions. For all the reasons mentioned above, it is necessary to study other variables that could predict the alterations in static plantar pressure distribution caused by bilateral HL, particularly under load-bearing conditions. While previous studies have focused on dynamic assessments, static plantar pressure analysis remains understudied, despite its clinical value in identifying compensatory patterns and morphological adaptations. Therefore, the objective of our research was to assess the relationship between foot morphological features and static plantar pressure distribution in individuals clinically diagnosed with bilateral HL, compared to subjects without this condition. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-2025-907/rc).

Methods

Study design

The research involved a total of 90 subjects (17 men and 73 women), 45 with HL bilateral and 45 with bilateral normal feet, with ages between 18 and 64 years old. Participants were included in the study using consecutive non-random sampling. A non-experimental, descriptive case-control investigation was employed at a biomechanics and movement centre, between October 2024 to January 2025.

For the control group, inclusion criteria were: ages 18–64 years, healthy individuals with no previous history of lower limb surgery, neutral alignment in both feet, and having signed the informed consent. For the case group, inclusion criteria were: ages 18–64 years, healthy individuals with bilateral HL, no prior lower limb surgery, and signed informed consent.

Exclusion criteria for both groups were: age below 18 years or above 64 years, current medication use, pregnancy or breastfeeding, previous lower limb surgery, failure to sign informed consent, or inability to understand study instructions.

Procedure

The study was conducted by an expert podiatrist. First, the subjects were interviewed to learn about aspects related to their general health, clinical characteristics, age, and sex. Later, with the subject barefoot and lightly clothed, they were weighed and measured, to determine their body mass index (BMI).

Following this, a clinical assessment was performed to evaluate the DF movement of the IMTFJ, which served as the diagnostic criterion for HL. This assessment was done while the individual was in a supine position. The clinician applied pressure beneath the first metatarsal head using one hand, without resistance, while simultaneously using the opposite hand to dorsiflex the hallux to its maximum range, until plantar flexion of the first metatarsal was detected. The normal DF angle of the IMTFJ is considered to be between 65° and 75° and the evaluation was based on whether this range could be reached with normal manual force. If the examiner was able to perform the DF movement, the test was considered negative (HL−). If this was not possible or greater force was required to achieve this DF movement, the test was considered positive (HL+). Depending on the result obtained in the evaluation, the subjects were assigned to the case group or the control group. A pressure platform (Neo-Plate, Herbitas. Spain) was used to carry out the study of plantar pressures (28) and the procedure by Ricardo Becerro-de Bengoa-Vallejo *et al.* was followed (29).

Static plantar pressure analysis

To assess and measure the distribution of plantar pressure, a portable platform was used, which was previously calibrated as specified by the maker. The platform measures 40 cm × 40 cm, with a thickness of 8 mm, with 4,096 resistive sensors and a total weight of 4 kilos. Each sensor recorded the pressure with a precision of 0.01 kPa. A frequency range of 100 to 500 Hz was used to measure the vertical force. Neo-Plate, Windows version (Laboratorios Herbitas SL, Valencia, Spain), a specific type of data collection software, was utilized to link the platform to the computer.

In line with the procedure proposed by Ricardo Becerro-de Bengoa-Vallejo *et al.* (29), each participant performed three static measurements, each lasting 10 seconds, with 30-second rest intervals between them to minimize fatigue. The subjects remained standing barefoot in a relaxed and upright position with the arms at their sides and gaze directed forward. The average of the three trials was used for data analysis.

The next items are the non-moving pressure analysis system that was recorded for each foot measurement: surface total, forefoot and heel area in cm^2, percentage of body weight supported by the legs, on the forefoot and on the heel, highest peak pressure in forefoot and heel measured in kPa. The results are shown in *Figure 1*.

Sample size method

Sample size calculation was performed using the G*Power 3.1.9.2 software based on the difference between two independent groups. Although the Mann-Whitney *U* test was used in the statistical analysis due to the non-normal distribution of data, the sample size was estimated using the Student's *t*-test model as a conservative approximation, using a two-tailed hypothesis, assuming a large effect size (Cohen's d =0.80), an alpha level of 0.05, a beta level of 0.20, and a desired statistical power of 80% (1−β). With an allocation ratio of 1:1, the minimum required sample size was determined to be 24 participants, with at least 12 individuals per group. However, a total of 90 participants were ultimately recruited through a consecutive, non-randomized sampling method. Participants were enrolled

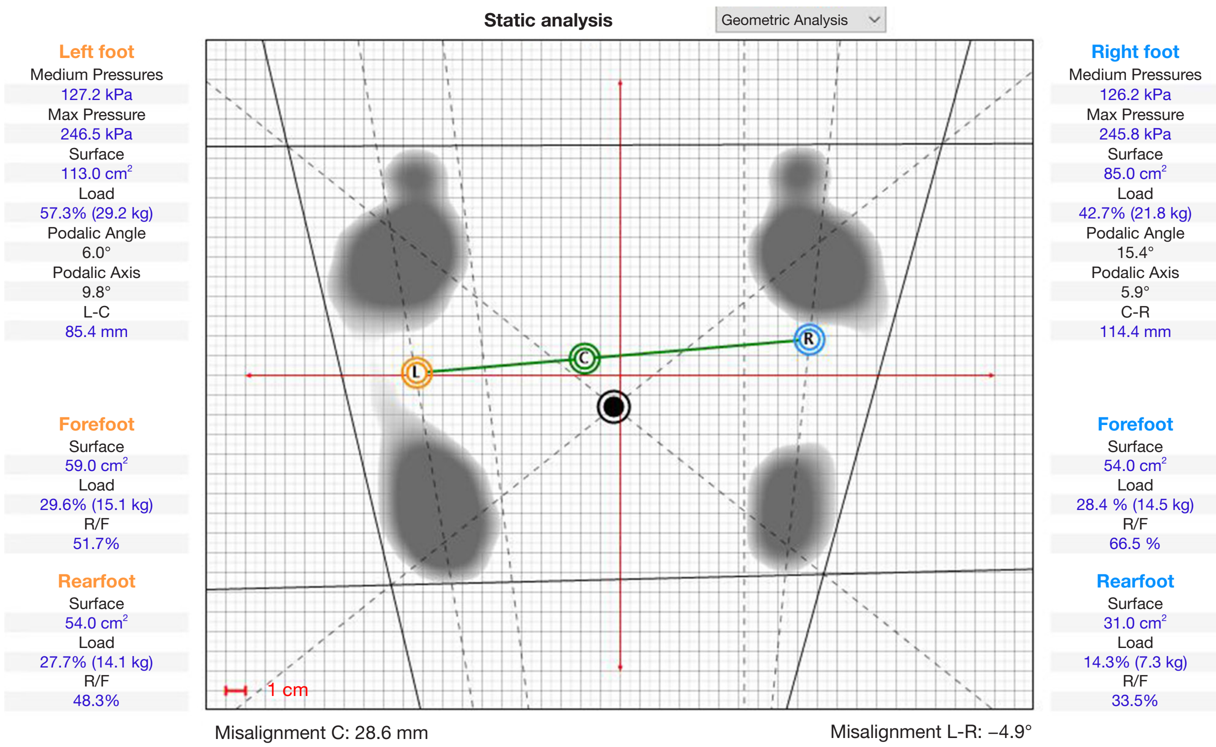

Figure 1 Quantitative analysis of static plantar pressure patterns via Neo-Plate software. C, center; C-R, center-right; L-C, left-center; L-R, left-right; R/F, rearfoot/forefoot.

from the Clínica del Pie (Madrid, Spain), and control subjects were matched by age and sex.

Ethical principles and legal practice considerations

Each subject participated voluntarily in the study and was therefore previously given a document with all the information about the research and the implications of their participation, as well as the opportunity to ask any questions or doubts about their participation. The informed consent was then signed.

This study was carried out in accordance with the ethical principles outlined in the Declaration of Helsinki and its subsequent amendments, and in compliance with Law 14/2007 of July 4 on Biomedical Research. The process of obtaining participant data was carried out under the principles of confidentiality and anonymity, following the state regulations on Personal Data Protection, Royal Decree 1720/2007 and the regulations of the European Regulation 2016/679. Likewise, the necessary measures were implemented to ensure the protection of personal data handled. The study was approved by the Institutional Review Board at the University of da Coruña (No. 2024-033). All participants provided written informed consent before taking part in the study.

Statistical analysis

The data analysis was conducted with the software IBM SPSS Statistics version 27.0.01. 0 for Windows (Armonk, NY, USA) and a P value <0.05 was deemed significant. For the variables, as mean, ranges of minimum to maximum, standard deviation values, percentages and absolute values were calculated. The Kolmogorov-Smirnov test was applied to assess the normality of distributions across all variables. Independent t-tests were utilized for variables that followed a normal distribution. For non-normally distributed data, the Mann-Whitney *U* test was applied to compare groups with and without HL.

Results

Regarding the sample of this research (n=90), the sociodemographic characteristics can be seen in *Table 1*,

Table 1 Demographic and clinical features of participants with or without bilateral HL

Characteristics	Total sample (N=90)	Bilateral HL (N=45)	Healthy group (N=45)	P value
Age (years)	26.43±5.44 [20–43]	26.18±4.77 [20–40]	26.69±6.08 [21–43]	0.804†
Weight (kg)	69.29±13.86 [50.00–98.00]	75.73±13.42 [53.00–98.00]	62.85±11.12 [50.00–95.00]	<0.001†
Height (cm)	165.39±7.66 [150.00–185.00]	164.00±8.37 [150.00–185.00]	166.73±6.70 [155.00–185.00]	0.022†
BMI (kg/m^2)	25.41±5.24 [17.51–39.26]	28.28±5.35 [21.08–39.26]	22.54±3.16 [17.51–32.87]	<0.001†
Sex				0.419‡
Male	17 (18.9)	10 (22.2)	7 (15.6)	
Female	73 (81.1)	35 (77.8)	38 (84.14)	
Foot size (EU)	38.89±2.19 [36–46]	38.82±2.32 [36–44]	38.96±2.08 [36–46]	0.415†

Data are presented as mean ± standard deviation [range] or n (%). †, Mann-Whitney U test applied; ‡, Fisher's exact test applied. A P value of <0.05 (with a 95% confidence interval) was considered statistically significant in all analyses. BMI, body mass index; cm, centimeter; HL, hallux limitus; kg, kilogram; N, number.

Table 2 Summary of static plantar pressure in participants with or without bilateral HL

Characteristics	Total sample (N=90)	Bilateral HL (N=45)	Healthy group (N=45)	P value
Left foot medium peak pressure (kPa)	138.20±9.74 [121.50–160.50]	141.73±9.12 [127.60–160.50]	134.62±8.38 [121.50–155.90]	<0.001†
Left maximum peak pressure (kPa)	242.65±6.86 [221.90–246.60]	245.10±1.83 [241.30–246.60]	241.57±8.32 [221.90–246.60]	0.262†
Left surface area (cm^2)	132.26±18.88 [102.00–186.00]	141.18±18.31 [118.00–186.00]	125.73±18.55 [102.00–178.00]	<0.001†
Body weight on the lower left limb (%)	48.85±3.11 [42.40–56.10]	49.70±2.83 [44.20–54.70]	48.78±3.24 [42.40–56.10]	0.347†
Left forefoot surface area (cm^2)	69.44±8.73 [57.00–96.00]	72.64±8.23 [60.00–92.00]	66.84±9.30 [57.00–96.00]	<0.001†
Body weight on the left forefoot (%)	26.45±2.99 [21.80–34.50]	26.45±3.10 [21.90–34.50]	26.58±2.82 [21.80–34.30]	0.500†
Left heel surface area (cm^2)	62.82±12.39 [41.00–96.00]	68.53±12.42 [48.00–96.00]	58.89±10.98 [41.00–93.00]	<0.001†
Body weight on the left heel (%)	22.40±2.92 [15.00–28.30]	23.24±3.23 [15.00–28.30]	22.21±2.60 [16.20–28.10]	0.039†
Right foot medium peak pressure (kPa)	142.49±6.11 [124.90–157.40]	142.98±7.43 [129.70–157.40]	140.49±6.13 [124.90–152.10]	0.142†
Right maximum peak pressure (kPa)	245.13±4.57 [221.10–246.60]	243.95±5.77 [221.10–246.60]	245.96±1.44 [239.50–246.60]	0.004†
Right surface area (cm^2)	134.06±16.83 [99.00–182.00]	141.33±13.67 [117.00–174.00]	126.47±18.16 [99.00–182.00]	<0.001†
Body weight on the lower right limb (%)	51.15±3.11 [43.90–57.60]	50.30±2.83 [45.30–55.80]	51.22±3.24 [43.90–57.60]	0.347†
Right forefoot surface area (cm^2)	69.05±9.66 [51.00–101.00]	71.49±7.26 [59.00–88.00]	65.84±11.29 [51.00–101.00]	0.007†
Body weight on the right forefoot (%)	27.22±3.55 [20.30–33.00]	25.98±3.63 [20.30–33.00]	27.92±3.03 [21.30–33.00]	0.007†
Right heel surface area (cm^2)	65.00±10.40 [32.00–100.00]	69.18±10.76 [32.00–86.00]	60.62±9.64 [45.00–100.00]	<0.001†
Body weight on the right heel (%)	23.95±3.34 [17.50–28.90]	24.46±3.24 [17.50–28.80]	23.33±2.87 [18.00–28.90]	0.041†

Data are presented as mean ±standard deviation [range]. †, Mann-Whitney U test was applied. A P value of <0.05 (with a 95% confidence interval) was considered statistically significant in all analyses. cm, centimeter; HL, hallux limitus; kPa, kilopascals; N, number.

highlighting the BMI data that was significant (P<0.001).

While examining the systems of static pressure, we noted notable differences (P<0.005) among the groups in the areas of the right and left surface zones, both heels, the medium peak pressure of the left foot, and the surface area of the left forefoot. The weight on the right forefoot was greater compared to the left foot (*Table 2*).

Discussion

The objective of our study was to assess the relationship between foot morphological characteristics and static plantar pressure distribution in individuals clinically diagnosed with bilateral HL, compared to healthy controls, using the procedure proposed by Ricardo Becerro-de Bengoa-Vallejo *et al.* (29). It is difficult to compare the results obtained in our study with others carried out previously, because although there are previous investigations that relate foot type to static plantar pressures in the adult population (30-32), as far as we know few focus on analysis in subjects with HL and specifically in statics. While dynamic analysis is valuable for understanding pressure during gait, static measurements offer a more stable and reproducible context to identify compensatory loading patterns at rest, such as increased heel contact or medial arch collapse, which are particularly relevant in the biomechanical assessment of HL (21,26,33,34).

The results showed significant differences between normal feet and feet with bilateral HL in medium peak pressure, which was greater in the left foot in the subjects with HL compared to the normal subjects. In addition, significant differences were observed in the surface areas in both feet. Subjects with HL showed a greater overall contact surface (in cm^2) compared to the control group. More specifically, both the forefoot and heel regions exhibited a significantly larger contact surface in the HL group. Although the forefoot surface area was generally larger than the heel within the HL group, as is expected physiologically, the heel area itself was significantly increased compared to healthy controls. This finding may reflect a compensatory strategy whereby individuals with HL, due to the restriction in DF of the IMTFJ, tend to offload the forefoot during static stance by shifting body weight posteriorly, leading to an increased ground contact surface at the heel. This redistribution of plantar support surface could serve to enhance postural stability or reduce discomfort in the forefoot. This finding can be interpreted as a compensatory biomechanical adaptation. The restriction of DF at the IMTFJ compromises the Windlass mechanism, reducing plantar fascia tension and contributing to the flattening of the medial longitudinal arch, which in turn increases heel contact (2,34,35). Additionally, HL has been associated with compensatory pronation and increased calcaneal eversion, expanding the heel contact surface (36). This redistribution of load may serve an antalgic function, minimizing pressure on painful or dysfunctional forefoot areas, while shifting support toward the heel, where we observed greater contact but relatively lower peak pressure.

Previous studies (20,22,37,38) on the effect of HL on plantar pressure but in this case in dynamics, conclude that in subjects with structural or functional HL, the maximum plantar pressure accumulates more and at a faster rate under the hallux and lesser toes, so this agrees that in statics the area with the greatest load surface is the forefoot. Fullin *et al.* (39) in their study where they analyzed plantar pressures but in this case in normal subjects they found a greater load in the forefoot (43%) with respect to the midfoot and hindfoot, as well as they found a higher mean pressure in the forefoot with a mean value of 59.1 kPa on the left side and 69.9 kPa on the right, while in our subjects with HL it had a higher mean value in the left foot than the right. Khan *et al.* (30) in their study on plantar pressure distribution in flat feet conclude that in these subjects the highest values for maximum pressure and surface area were located at the medial level. Additionally, Buldt *et al.* (40), who examined plantar pressure between subjects with normal, hollow and flat feet, revealed that pressure and force distribution varied significantly between the three groups in distinct regions of the foot. Therefore, taking into account our results and those of previous studies, we propose that static plantar pressure analysis may serve as a complementary diagnostic tool in clinical practice. While the diagnosis of HL is primarily clinical, plantar pressure measurements provide objective, quantifiable data on load distribution and foot-ground interaction. These insights help characterize the biomechanical adaptations associated with HL, such as altered load transfer to the heel or forefoot, and can inform more tailored treatment strategies, in order to improve the gait and therefore the quality of life of these subjects.

The results show a different behavior in each foot, as can also be observed in the percentage of weight supported by each one, since in the left foot a greater percentage of weight is observed in the heel, while the right foot loads more on the forefoot than on the heel. Therefore, according to our results we can determine that the two feet of the same subject are not equal, nor do they behave or adapt in the same way. These asymmetries may reflect differences in joint mobility severity, habitual limb use, or postural dominance. While we did not assess leg preference or dominance formally, previous studies suggest that even in bilateral pathologies, functional asymmetries may persist. These findings highlight the importance of individualizing treatment for each foot and suggest that evaluating limb dominance could be valuable in future research.

Although overweight was not a primary objective of the present study, a statistically significant difference in BMI was observed between groups (P<0.001). This secondary finding may partially explain the altered plantar pressure patterns found in participants with HL, a condition that has been reported by several authors as an aggravating factor in the deterioration of foot health (41-46). Cimolin *et al.*, in their study on differences in plantar pressure between obese and non-obese adolescents, concluded that obese subjects showed higher values for all regions, with the exception of the medial area of the hindfoot, for which the values were similar between the two groups (47). Naderi *et al.*, in their study analyzing the association of obesity with high dynamic plantar pressure, determined that overweight is linked to increased maximum pressure levels in the foot and with an impulse under different areas of the foot. This elevated pressure comes from having a high BMI, while individuals with a lower body weight tend to have stronger muscles, which can also help normalize the pressure in the foot (45). While we cannot conclude causality, these findings highlight the relevance of routine foot assessments in overweight individuals with HL. Interventions such as plantar orthoses may assist in redistributing pressure and improving foot function, potentially helping to prevent secondary complications and enhance quality of life.

Our study has limitations. First, sex was not used as a matching criterion, and our sample included a higher proportion of female subjects than males. This imbalance may have influenced the outcomes, as sex is a known factor associated with foot structure and the presence of HL. Future studies should consider stratifying or matching by sex to determine whether sex-specific differences affect plantar pressure distribution in individuals with HL. Secondly, the portable platform used only records vertical force at a sampling rate 60 Hz. Therefore, future research should consider analyzing additional force components, such as horizontal shear forces, and employing higher sampling frequencies. These enhancements could provide deeper insights into the dynamics of foot sole movements, which may be crucial for understanding the biomechanics of foot motion. Associated biomechanical data, such as electromyography, were not collected, nor were other joints, such as the knee or hip assessed, which may be affected by the compensatory mechanisms generated by the presence of HL. Additionally, although static plantar pressure analysis provides a reliable and reproducible measure of weight distribution and foot morphology, it does not capture dynamic aspects such as gait mechanics or propulsion, which are also relevant in the clinical behavior of HL. This may represent a limitation, and future research should integrate dynamic assessments to offer a more complete understanding of plantar loading and compensatory strategies in motion. Therefore, we cannot draw conclusions about how plantar pressures may influence lower limb function. Moreover, weight and BMI were significantly higher in the HL group compared to controls, which may have influenced plantar pressure values. Although this reflects a real-world clinical scenario, we acknowledge that direct comparison of unadjusted pressure values between groups may introduce confounding effects. Future studies should consider adjusting for these anthropometric variables or conducting stratified analyses to better isolate the impact of HL. Despite these limitations, our study provides preliminary insights into static plantar pressure distribution patterns in subjects with HL, using a reproducible clinical protocol. Although our findings do not establish direct clinical outcomes, they suggest that morphological and pressure differences in this population could have implications for assessment and intervention strategies. These results support the need for further investigation to determine whether plantar pressure mapping could contribute to individualized therapeutic approaches in people with HL, allowing for orthopedic treatments that better redistribute plantar loads. Continuing this line of research can help optimize diagnosis and treatment, with the goal of improving foot biomechanics and patient quality of life.

Conclusions

Individuals with bilateral HL showed variations in static plantar pressure distribution and contact surface area in the heel and forefoot compared to the control group. These alterations may reflect biomechanical compensations that affect postural alignment and foot function. While this study does not directly assess dynamic gait parameters or clinical outcomes, the static pressure mapping protocol used provides reproducible morphological data that could support the identification of compensatory mechanisms in HL. These findings may help inform future research aimed at designing individualized treatment strategies, such as custom foot orthoses or adapted footwear, that target specific pressure redistribution patterns to potentially improve comfort, balance, and long-term foot function in patients with HL.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-2025-907/rc

Data Sharing Statement: Available at https://qims.amegroups.com/article/view/10.21037/qims-2025-907/dss

Funding: This research was funded by the Spanish Ministry of Science and Innovation through the project (No. PID2023-149353OB-I00).

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-2025-907/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments and was approved by the Institutional Review Board at the University of da Coruña (No. 2024-033). All participants provided written informed consent before taking part in the study.

References

1. Drago JJ, Oloff L, Jacobs AM. A comprehensive review of hallux limitus. J Foot Surg 1984;23:213-20.
2. Viehöfer AF, Vich M, Wirth SH, Espinosa N, Camenzind RS. The Role of Plantar Fascia Tightness in Hallux Limitus: A Biomechanical Analysis. J Foot Ankle Surg 2019;58:465-9.
3. Clough JG. Functional hallux limitus and lesser-metatarsal overload. J Am Podiatr Med Assoc 2005;95:593-601.
4. Michaud TC, Nawoczenski DA. The influence of two different types of foot orthoses on first metatarsophalangeal joint kinematics during gait in a single subject. J Manipulative Physiol Ther 2006;29:60-5.
5. Rosemberg DL, Gustafson JA, Bordignon G, Bohl DD, Leporace G, Metsavaht L. Biokinetic Evaluation of Hallux Valgus during Gait: A Systematic Review. Foot Ankle Int 2023;44:763-77.
6. Donatelli RA. Abnormal biomechanics of the foot and ankle. J Orthop Sports Phys Ther 1987;9:11-6.
7. Coughlin MJ, Jones CP. Hallux valgus: demographics, etiology, and radiographic assessment. Foot Ankle Int 2007;28:759-77.
8. Merker J, Hartmann M, Kreuzpointner F, Schwirtz A, Haas JP. Pathophysiology of juvenile idiopathic arthritis induced pes planovalgus in static and walking condition: a functional view using 3D gait analysis. Pediatr Rheumatol Online J 2015;13:21.
9. Sánchez-Gómez R, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Calvo-Lobo C, Navarro-Flores E, Palomo-López P, Romero-Morales C, López-López D. Reliability Study of Diagnostic Tests for Functional Hallux Limitus. Foot Ankle Int 2020;41:457-62.
10. Menz HB, Auhl M, Tan JM, Buldt AK, Munteanu SE. Centre of pressure characteristics during walking in individuals with and without first metatarsophalangeal joint osteoarthritis. Gait Posture 2018;63:91-6.
11. Meyr AJ, Berkelbach C, Dreikorn C, Arena T. Descriptive Quantitative Analysis of First Metatarsal Sagittal Plane Motion. J Foot Ankle Surg 2020;59:1244-7.
12. Padrón L, Bayod J, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias M, López-López D, Casado-Hernández I. Influence of the center of pressure on baropodometric gait pattern variations in the adult population with flatfoot: A case-control study. Front Bioeng Biotechnol 2023;11:1147616.
13. Kunnasegaran R, Thevendran G. Hallux Rigidus: Nonoperative Treatment and Orthotics. Foot Ankle Clin 2015;20:401-12.
14. Grady JF, Axe TM, Zager EJ, Sheldon LA. A retrospective analysis of 772 patients with hallux limitus. J Am Podiatr Med Assoc 2002;92:102-8.
15. Manfredi-Márquez MJ, Tavara-Vidalón SP, Tavaruela-Carrión N, Gómez Benítez MÁ, Fernandez-Seguín LM, Ramos-Ortega J. Study of Windlass Mechanism in the Lower Limb Using Inertial Sensors. Int J Environ Res Public Health 2023;20:3220.
16. Biz C, Maso G, Malgarini E, Tagliapietra J, Ruggieri P.

Hypermobility of the First Ray: the Cinderella of the measurements conventionally assessed for correction of Hallux Valgus. Acta Biomed 2020;91:47-59.
17. Singh D, Biz C, Corradin M, Favero L. Comparison of dorsal and dorsomedial displacement in evaluation of first ray hypermobility in feet with and without hallux valgus. Foot Ankle Surg 2016;22:120-4.
18. Gilheany MF, Landorf KB, Robinson P. Hallux valgus and hallux rigidus: a comparison of impact on health-related quality of life in patients presenting to foot surgeons in Australia. J Foot Ankle Res 2008;1:14.
19. Fung J, Sherman A, Stachura S, Eckles R, Doucette J, Chusid E. Nonoperative Management of Hallux Limitus Using a Novel Forefoot Orthosis. J Foot Ankle Surg 2020;59:1192-6.
20. Cuevas-Martínez C, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, et al. Hallux Limitus Influence on Plantar Pressure Variations during the Gait Cycle: A Case-Control Study. Bioengineering (Basel) 2023;10:772.
21. Cuevas-Martínez C, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Casado-Hernández I, Turné-Cárceles O, Pérez-Palma L, Martiniano J, Gómez-Salgado J, López-López D. Analysis of Static Plantar Pressures in School-Age Children with and without Functional Hallux Limitus: A Case-Control Study. Bioengineering (Basel) 2023;10:628.
22. Van Gheluwe B, Dananberg HJ, Hagman F, Vanstaen K. Effects of hallux limitus on plantar foot pressure and foot kinematics during walking. J Am Podiatr Med Assoc 2006;96:428-36.
23. Cuevas-Martínez C, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Navarro-Flores E, Pérez-Palma L, Martiniano J, López-López D, Casado-Hernández I, Gómez-Salgado J. Assessment and indicators of hallux limitus related with quality of life and foot health in school children. Front Pediatr 2023;11:1295832.
24. Cuevas-Martínez C, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, Casado-Hernández I, Navarro-Flores E, Pérez-Palma L, Martiniano J, Gómez-Salgado J, López-López D. Hallux Limitus Influence on Plantar Pressure Variations during the Gait Cycle: A Case-Control Study. Bioengineering (Basel) 2023;10:772.
25. Sanchez PJ, Grady JF, Lenz RC, Park SJ, Ruff JG. Metatarsus Primus Elevatus Resolution After First Metatarsophalangeal Joint Arthroplasty. J Am Podiatr Med Assoc 2018;108:200-4.
26. Bryant A, Tinley P, Singer K. Plantar pressure distribution in normal, hallux valgus and hallux limitus feet. The Foot 1999;9:115-9.
27. Okamura K, Egawa K, Ikeda T, Fukuda K, Kanai S. Relationship between foot muscle morphology and severity of pronated foot deformity and foot kinematics during gait: A preliminary study. Gait Posture 2021;86:273-7.
28. Painceira-Villar R, García-Paz V, Becerro de Bengoa-Vallejo R, Losa-Iglesias ME, López-López D, Martiniano J, Pereiro-Buceta H, Martínez-Jiménez EM, Calvo-Lobo C. Impact of Asthma on Plantar Pressures in a Sample of Adult Patients: A Case-Control Study. J Pers Med 2021;11:1157.
29. Becerro de Bengoa Vallejo R, Losa Iglesias ME, Zeni J, Thomas S. Reliability and repeatability of the portable EPS-platform digital pressure-plate system. J Am Podiatr Med Assoc 2013;103:197-203.
30. Khan F, Chevidikunnan MF, BinMulayh EA, Al-Lehidan NS. Plantar pressure distribution in the evaluation and differentiation of flatfeet. Gait Posture 2023;101:82-9.
31. Buldt AK, Forghany S, Landorf KB, Levinger P, Murley GS, Menz HB. Foot posture is associated with plantar pressure during gait: A comparison of normal, planus and cavus feet. Gait Posture 2018;62:235-40.
32. Hagedorn TJ, Dufour AB, Riskowski JL, Hillstrom HJ, Menz HB, Casey VA, Hannan MT. Foot disorders, foot posture, and foot function: the Framingham foot study. PLoS One 2013;8:e74364.
33. Shurnas PS. Hallux rigidus: etiology, biomechanics, and nonoperative treatment. Foot Ankle Clin 2009;14:1-8.
34. HICKS JH. The mechanics of the foot. II. The plantar aponeurosis and the arch. J Anat 1954;88:25-30.
35. Hicks JH. The Foot As A Support. Cells Tissues Organs 1955;25:34-45.
36. Roukis TS, Scherer PR, Anderson CF. Position of the first ray and motion of the first metatarsophalangeal joint. J Am Podiatr Med Assoc 1996;86:538-46.
37. Bryant A, Tinley P, Singer K. A comparison of radiographic measurements in normal, hallux valgus, and hallux limitus feet. J Foot Ankle Surg 2000;39:39-43.
38. Zammit GV, Menz HB, Munteanu SE, Landorf KB. Plantar pressure distribution in older people with osteoarthritis of the first metatarsophalangeal joint (hallux limitus/rigidus). J Orthop Res 2008;26:1665-9.
39. Fullin A, Caravaggi P, Picerno P, Mosca M, Caravelli S, De Luca A, Lucariello A, De Blasiis P. Variability of Postural Stability and Plantar Pressure Parameters in Healthy Subjects Evaluated by a Novel Pressure Plate. Int J Environ Res Public Health 2022;19:2913.
40. Buldt AK, Forghany S, Landorf KB, Murley GS, Levinger

P, Menz HB. Centre of pressure characteristics in normal, planus and cavus feet. J Foot Ankle Res 2018;11:3.
41. Dufour AB, Losina E, Menz HB, LaValley MP, Hannan MT. Obesity, foot pain and foot disorders in older men and women. Obes Res Clin Pract 2017;11:445-53.
42. Ko S, Stenholm S, Ferrucci L. Characteristic gait patterns in older adults with obesity--results from the Baltimore Longitudinal Study of Aging. J Biomech 2010;43:1104-10.
43. Cau N, Cimolin V, Galli M, Precilios H, Tacchini E, Santovito C, Capodaglio P. Center of pressure displacements during gait initiation in individuals with obesity. J Neuroeng Rehabil 2014;11:82.
44. Kim D, Lewis CL, Silverman AK, Gill SV. Changes in dynamic balance control in adults with obesity across walking speeds. J Biomech 2022;144:111308.
45. Naderi A, Baloochi R, Rostami KD, Fourchet F, Degens H. Obesity and foot muscle strength are associated with high dynamic plantar pressure during running. Foot (Edinb) 2020;44:101683.
46. Vuurberg G, Altink N, Rajai M, Blankevoort L, Kerkhoffs GMMJ. Weight, BMI and stability are risk factors associated with lateral ankle sprains and chronic ankle instability: a meta-analysis. J ISAKOS 2019;4:313-27.
47. Cimolin V, Capodaglio P, Cau N, Galli M, Pau M, Patrizi A, Tringali G, Sartorio A. Foot-type analysis and plantar pressure differences between obese and nonobese adolescents during upright standing. Int J Rehabil Res 2016;39:87-91.

Cite this article as: Tovaruela-Carrión N, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, López-López D, Gómez-Salgado J, Bayod López J. Effects of plantar static pressure distribution in subject with bilateral hallux limitus: a detailed case-control study. Quant Imaging Med Surg 2025;15(9):8153-8162. doi: 10.21037/qims-2025-907